The First Meeting of Cold Region Landslides Network, Harbin, China. 2012

Initial observations of the 11 June 2012 rock/ice avalanche, Lituya Mountain, Alaska

Marten Geertsema(1)

1) Ministry of Forests, Lands, and Natural Resource Operations, 1044 5th Ave, Prince George BC, Canada, 1- 250 565-6923

Abstract On 11 June 2012, a large volume of rock and ice collapsed on the eastern flank of Lituya Mountain, Alaska (approximately 58^0 48' N; 137^0 26' W). The displaced mass fragmented as it travelled 2.5 km down the steep ($35\text{-}40^0$) eastern flank of the mountain. The landslide flowed for another 6.5 km over a tributary of John Hopkins Glacier. The total elevation drop is estimated at 2.5 km and the total travel distance was 9 km, yielding a travel angle of 15.5^0. The areal extent of the landslide is 7-8 km^2. The landslide generated a significant air blast which travelled in a straighter trajectory than the landslide, and resulted in an airborne deposit more than 500 m above the rock avalanche debris. The landslide triggered seismic signals of 3.4 and 3.7 M, as interpreted by US and Canadian earthquake agencies, respectively.

Keywords rock / ice avalanche, glacier, Alaska, Glacier Bay National Park and Preserve, Lituya Mountain

Introduction

On 11 June, 2012 22:23:53 UTC atypical seismic signals were recorded at a number of stations in Alaska, and adjacent areas in Canada (Fig. 1). The author of the popular AGU landslide blog (Prof. D. Petley), one of several to notice the curious signals (Fig. 2), documented the event and sent out an alert for what was thought to be a large rock slide somewhere near the British Columbian/Alaskan border (http://blogs.agu.org/landslideblog/2012/06/14/another-very-large-landslide-this-time-on-the-canada-alaska-border-can-you-help/). This alert was forwarded to Canadian Parks officials by me. According to the blog, K. Delaney and Prof. S.G. Evans (University of Waterloo, Canada) first discovered the landslide on Landsat imagery. To my knowledge the landslide was first observed and photographed in the field by pilot Drake Olson (Haines, Alaska) on 9 July 2012.

What Drake Olson photographed was a large rock/ice avalanche on the east side of Lituya Mountain in Glacier Bay National Park and Preserve. The landslide covered between 7 and 8 square kilometres of mountainside and glacier, and travelled 9 km.

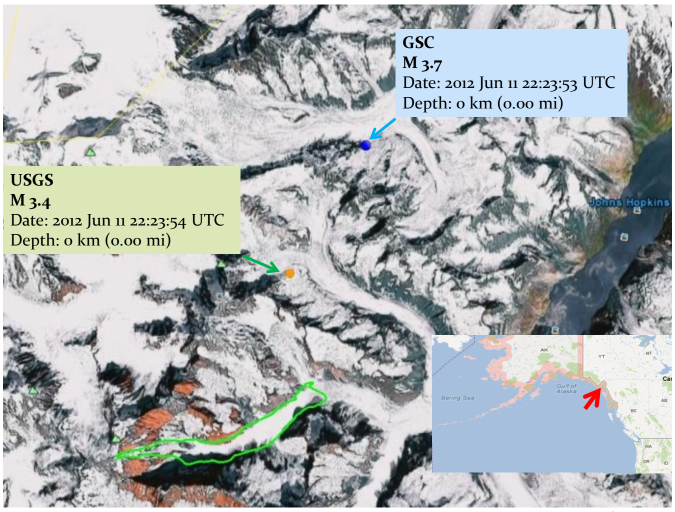

Figure 1 Location of the landslide in southeastern Alaska (green outline) in relation to triangulated signals from the US and Canadian agencies. Google image.

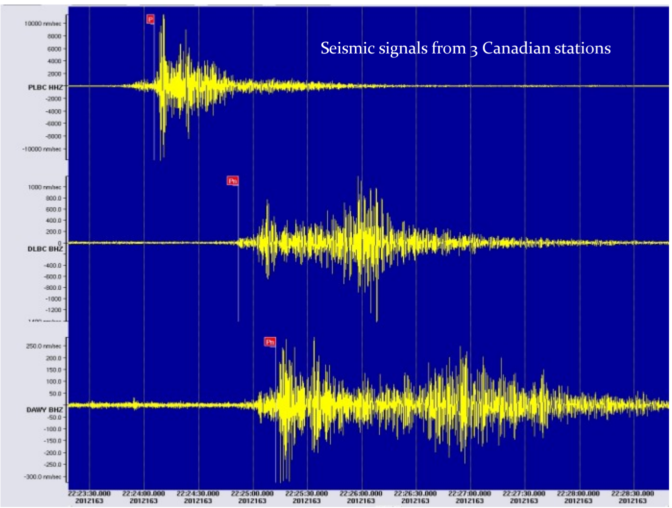

Figure 2 Seismic signals recording the 11 June 2012 Lituya Mountain landslide from three Canadian stations – plot provided by Dr. Garry Rogers, Geological Survey of Canada.

Setting

Physical Environment

Glacier Bay National Park and Preserve is characterized by high, rugged mountains (approaching 4700 m asl) and glaciated valleys, with glaciers extending to tidewater.

The region is tectonically active, and includes the major Fairweather Fault, and a number of lesser faults (Gehrels and Berg 1992). David A Brew, U.S. Geological Survey (written communication) mapped the precipitous cliff, at the location of the zone of depletion, as layered gabbro - Oligocene hornblende-pyroxene gabbro (Togh) of the Crillon-La Perouse Plutonic Belt.

While the climate is maritime (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?akglac), the elevation gradient results in a heavy snow accumulation and predicted permafrost at higher altitudes (Gruber 2011). Permafrost should be especially present where windswept and steep surfaces accumulate less (insulating) snow.

Perhaps the Lituya area is most famous for its more than 500 m high landslide displacement wave that happened in 1958 (Pararas-Carayannis 1999).

Landslide description

Dimensions

The Lituya Bay landslide, its areal extent constrained by low resolution Landsat 7 imagery (Fig. 3), appears to be at least 7 km^2 in area. The landslide is approximately 9 km long (L). There appear to be some discrepancies between Digital Elevation Models, but the elevation of the landslide crown appears to be somewhere up to 3300 m asl. The tip of the landslide is approximately 800 m asl – with a total elevation difference of up to 2500 m (H).

The inverse tan of the ratio H/L (the elevation difference between the crown and the tip (H) and the length (L) along central path of the landslide) yields a travel angle of up to 15.5^0, consistent with values determined for rock avalanches in the data sets of Evans and Clague (1999) and Geertsema and Cruden (2008).

A long profile of the landslide (along its central path) shows the contrast in slope gradient between rock and glacier surfaces (Fig. 4). Extremely steep slopes at the main scarp are measured at more than 55^0 on the 90 m DEM. The slope of the travel path in the first kilometre averages 45^0 and the average is just below 40^0 for the first 2.5 km. The remaining 6.5 km of travel distance averages under 5^0, and represents travel on the valley glacier.

The steep source area appears to be about 200 m wide near the crown (Fig. 5). Without higher resolution pre and post landslide DEMs, determining a precise source volume is impossible. The landslide is much narrower in the zone of depletion (source area) than in the zone of accumulation on the glacier. Once the moving mass flowed on the glacier, the deposit, although remaining topographically constrained, widened to 1 km.

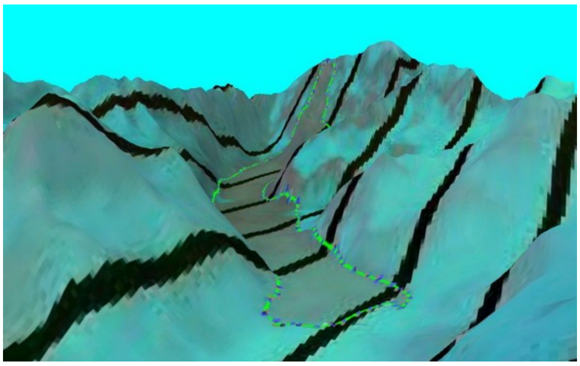

Figure 3 Landsat 7 image showing the landslide (outlined in green) 6 days after it occurred. The image is draped over a 90 m DEM.

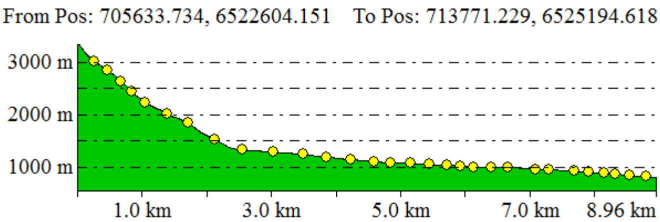

Figure 4 Long profile along the central path of the 2012 Lituya landslide. According to the 90m DEM, movement over the first 2.5 km, on the slope of Lituya Mountain is just below 40^0. The remaining 6.5 km, travelled on the valley glacier is less than 5^0.

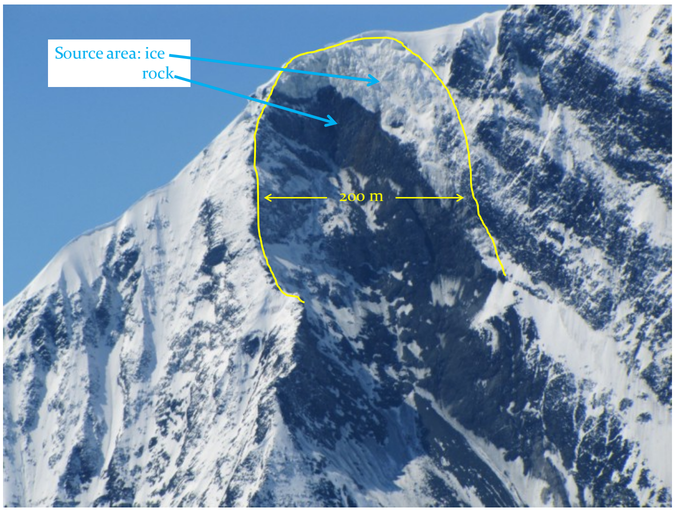

Figure 5 The source area, some 200 m wide, shows evidence of both ice and rock fall. The rock is likely a hornblende-pyroxene gabbro (source: Dave Brew). Original photo by Drake Olson.

I could not calculate the volume loss in the zone of depletion, nor the thickness of the deposit on the glacier from the available data. If one assumes most of the debris was deposited on approximately 5-6 km^2 of glacier, average thicknesses of 1 to 10 m would yield volumes of 5 million to 60 million m^3. The average debris thickness of similar landslides (triggered by the Denali Earthquake in 2002) was 3 m (Jibson et al, 2006). Such a thickness could yield a volume of up to 18 million m^3. From Drake Olson's photos it is clear that the deposit varied in thickness, with bare glacial surfaces evident in the thinner zones (Fig. 6), and considerably thicker deposits elsewhere (Fig. 7). Detailed calibrated stereographic imagery or LiDAR is needed to determine the thickness, and the volume of the debris.

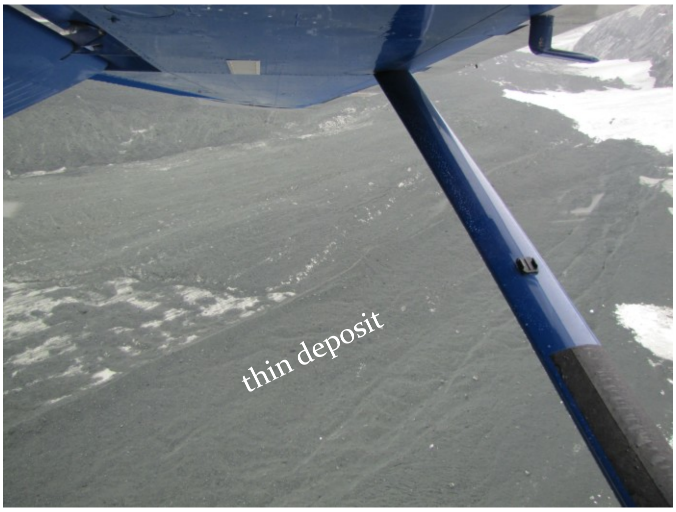

Figure 6 Thin debris cover on the glacier. Note bare ice patches. Also note post-landslide snow avalanches (right margin of photo). Original photo by Drake Olson.

Figure 7 Thicker debris on the glacier. Original photo by Drake Olson.

Landslide velocity

The long runout and height of fall of the landslide alone are clues that the movement was extremely rapid (see Cruden and Varnes (1996) for velocity scale). Run up, super-elevation (in outer bends (Fig. 8)), and radius of curvature are metrics by which to calculate velocity. Without accurate elevation control of the deposit margins the calculations are unreliable.

The initial cliff collapse and movement on the 55^0 and then 40^0 slopes would have been the most rapid. Much of this movement may have been characterized by falling and sliding. In 2002 the Denali earthquake triggered rock slides onto glaciers with the longest one 11 km (Jibson et al. 2006). At McGinnis Peak, one of the landslides, minimum runup velocities were calculated at 200 km/hour 4 km from the source and a super-elevation calculation yielded velocities of 150 km / hour 5 km from the source.

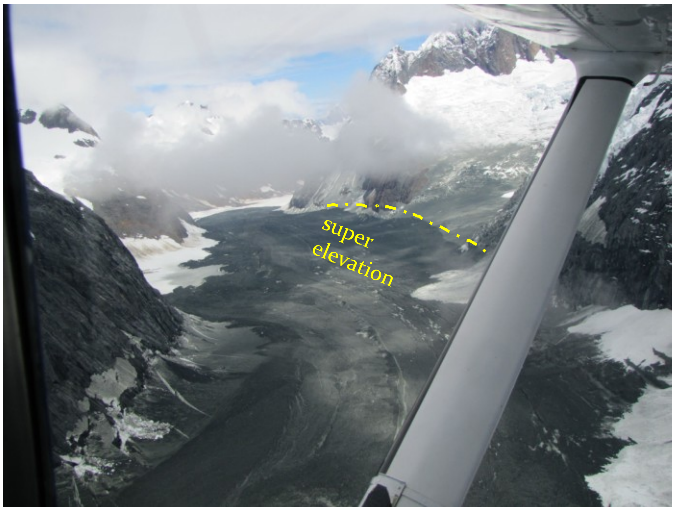

Figure 8 Super-elevation of unknown height. Details of height and curvature can be used to estimate velocity. Original photo by Drake Olson.

Dust plume and air pressure wave

A large plume of dust travelled in a straighter trajectory than the landslide which followed the geometry of the valley (Fig. 9). Jibson et al (2006) noted dust up to 70 m high on valley walls. For this landslide I estimate dust (or at least finer material than the flow debris) to be at least 500 m above the landslide deposit (Fig. 10). According to the pilot, Drake Olson (telephone communication), fist sized pebbles even occurred above this zone in what he described to be a salt and pepper effect. Xu et al. (2012) describe an air pressure wave zone at the outer margins of the gigantic 2000 Yigong rock slide – debris avalanche in Tibet. There gravel up to 40 cm in size was scattered throughout this zone, with trees flattened and some blown horizontally tens to hundreds of metres. There were no trees to produce evidence of this phenomenon here, but the high dust cloud and the peppering of gravel above it, suggest a significant air blast from a compressed air pressure wave may have occurred.

Detailed imagery obtained in “snow free” conditions and field observations will be required to characterize this zone.

Causes and triggers?

At this point it is difficult to speculate on what might have caused this landslide and at least one additional one on Hubbard Glacier, some 180 km to the northwest of Lituya Mountain. There appears to be an increase of large rock slides at high elevations around the world (e.g. Geertsema et al 2006, Huggel et al 2010, 2012).

This holds true especially for recently deglaciated zones (e.g. Holm et al. 2004). The effects of glacial conditioning should not be discounted. Geertsema and

Chiarle (In Press) suggests this happens in four ways: 1. glaciers deepen and widen valleys; 2. the ice loading results in stress fractures; 3. debuttressing during glacial thinning; and 4 stress release as manifested by joint expansion.

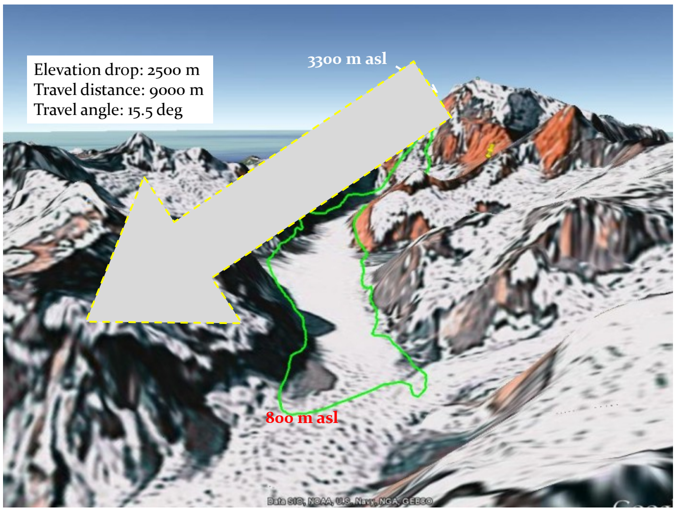

Figure 9 Annotated Google Earth image showing the topographically constrained rock avalanche (green outline) and the higher and straighter trajectory of the dust cloud (arrow) for illustrative purposes.

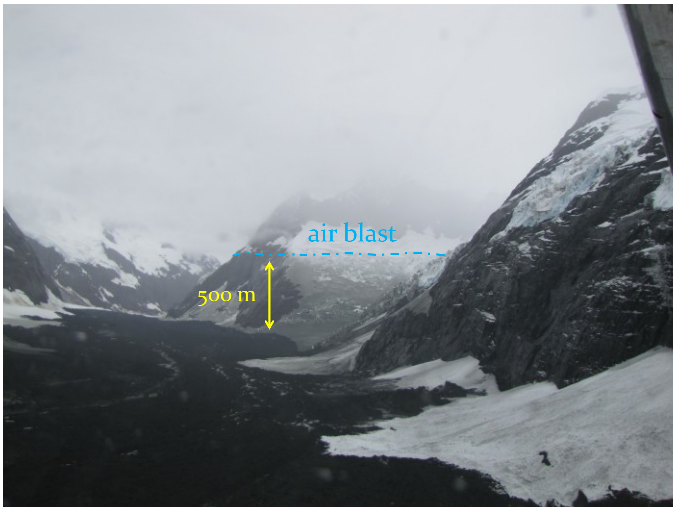

Figure 10 "Dust" coating some 500 m above the landslide deposit. Drake Olson related that he saw a peppering of fist-sized stones above this limit. Original photo by Drake Olson.

The effect of permafrost degradation on rock instability is also receiving more attention globally (e.g. Harris et al. 2001, Gruber and Haeberli 2007), in part because of an increase in alpine rock movements. Gruber (2011) created a global permafrost layer available for viewing in Google Earth. Many rock slide initiation zones plot within the permafrost zone of this layer, including the Lituya Mountain landslide (Fig. 11).

Another potential contribution is an above average snow pack (as per Joel Curtis, meteorologist with the National Weather Service, Juneau) combined with a delayed rapid melt. Delayed rapid melt of thick snow packs is commonly associated with landslides.

Other considerations include geologic conditions such as seismic conditioning, a long period of gravitational sagging, and other factors.

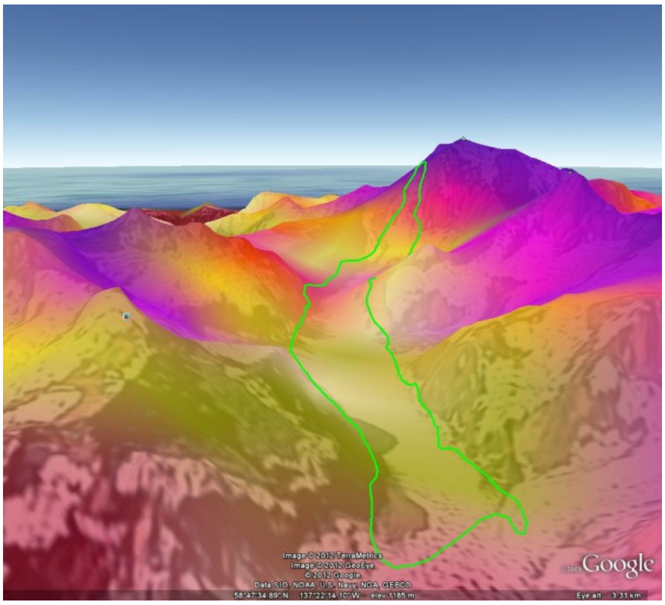

Figure 11 Annotated Google Earth image showing the 2012 Lituya Mountain rock avalanche (green outline) and the permafrost probability layer created by Gruber (2011). The purple colour indicates a strong probability of permafrost.

Conclusions and future work

The June 11 landslide was a remarkable event and one of the largest recent rock/ice avalanches in North America. Some seismically triggered events had longer runouts, and certainly lahars (volcanically triggered landslides) can be orders of magnitude bigger (e.g. the event associated with the Mount Saint Helen's eruption).

The landslide initiated in a predicted permafrost zone, perhaps during a period of delayed melting of a thicker than average snowpack. Movement began as an ice and rock fall in the initiation zone, then slid and flowed on a 40^0 slope for 2.5 km, before flowing over the surface of a valley glacier for another 6.5 km. An aerial deposit of dust and small stones appears to have coated the mountain side at least 500 m above the landslide.

Questions yet to be answered:

- Cause and triggers – information of rock mass properties in the source area, snow pack and forensic climate analysis, permafrost role
- Velocities (accurate field and aerial imagery measurements)
- Can we expect more, where and under what conditions?
- Impacts on glacier dynamics

Acknowledgments

The photos from and conversations with Drake Olson are greatly appreciated. Garry Rogers provided the plot and interpretation of the seismic signals. I had fruitful discussions with Glacier Bay Park staff including Lisa Etherington, Susan Boudreau, Dave Nemeth, and Lewis Sharman, with Joel Curtis from the National Weather Service and also with Brian Menounos of the University of Northern British Columbia. US Geological Survey scientists Ed Harp and David Brew provided excellent information on landslides and bedrock geology, respectively.

References

Cruden DM, Varnes DJ. 1996. Landslide types and processes. In: Turner AK, Schuster RL (eds) Special report 247: landslides investigation, mitigation. National Research Council, Transportation Research Board, Washington D.C., pp 36–75.

Evans, S.G. and Clague, J.J., 1999. Rock avalanches on glaciers in the Coast and St. Elias Mountains, British Columbia. In: Slope stability and landslides. Proceedings, 13th Annual Geotechnical Society Symposium, Vancouver, B.C., pp. 115-123.

Geertsema M, Chiarle M. In Press. Mass Movement Causes: Glacier Thinning. In Treatise on Geomorphology.

Geertsema M, Clague JJ, Schwab JW, Evans SG. 2006. An overview of recent large landslides in northern British Columbia, Canada. Engineering Geology 83: 120-143.

Geertsema M, Cruden DM. 2008. Travels in the Canadian Cordillera. 4th Canadian Conference on Geohazards, Quebec PQ.

Gehrels GE, Berg, HC. 1992. Geologic map of Southeastern Alaska. USGS. Miscellaneous Investigations Series Map I-1867.

Gruber S. 2011. Derivation and analysis of a high resolution estimate of global permafrost zonation. The Cryosphere Discussions 5: 1547-1582.

Gruber S, Haeberli W. 2007. Permafrost in steep bedrock slopes and its temperature-related destabilization following climate change. Journal of Geophysical Researches. 112: F02S18.

Harris C, Davies MCR, Etzelmu¨ller B (2001) The assessment of potential geotechnical hazards associated with mountain permafrost in a warming global climate. Permafost Periglacial Processes 12:145–156.

Holm K, Bovis MJ, Jakob M. 2004. The landslide response of alpine basins to post-Little Ice Age glacial thinning and retreat in southwestern British Columbia. Geomorphology 57:201–216

Huggel, C., Allen, S., Deline, P., Fischer, L., Noetzli, J. and Ravanel, L. (2012), Ice thawing, mountains falling—are alpine rock slope failures increasing?. Geology Today, 28: 98–104. doi: 10.1111

Huggel, C., Salzmann, N., Allen, S. K., Caplan-Auerbach, J., Fischer, L., Haeberli, W., Larsen, C., Schneider, D., Wessels, R. (2010) Recent and future warm extreme events and high-mountain slope stability. Philosophical Transactions of the Royal Society A 368: 2435-2459.

Jibson RW, Harp EL, Schulz W, Keefer DK. 2006. Large rock avalanches triggered by the M 7.9 Denali Fault, Alaska, earthquake of 3 November 2002. Engineering Geology 83: 144-160.

Pararas-Carayannis, G. 1999. Analysis of mechanism of the giant tsunami generation in Lituya Bay on July 9, 1958. In: Abstracts, Tsunami Symp. 1999, May 25–27, 1999, Honolulu, Hawaii. http://users.tpg.com.au/users/tps-seti/tsym.html (Accessed May 2010).

Xu Q, Shang Y, van Asch T, Wang S, Zhang Z, Dong X. 2012. Observations from the large, rapid Yigong rock slide – debris avalanche, southeast Tibet. Canadian Geotechnical Journal 49: 589-606.